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Final Reports

NASA Grant No. NAGW 1991
Studies of Triton and the Pluto-Charon System

and

NASA Grant No. NAGW 3093
Modeling and Monitoring of the Pluto-Charon System

Principal investigator
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Location where research was performed
Institute for Astronomy, University of Hawaii

History

The two grants described in this Final Report represent the continuation of Pluto-Charon observational work that was started in 1984 under the large block grant to the University of Hawaii (NGL 12-001-057) with the Institute for Astronomy Director acting as Principal Investigator. NAGW 1991 came into existence when the block grant was broken into individual grants with individual Principal Investigators, and it funded the continued observation of Pluto-Charon mutual events through the end of the season in 1990, as well as Voyager 2 support observations of Triton prior to the Neptune encounter in 1989.

Due to the need to establish a photometric baseline representing Pluto and Charon in an uneclipsed or unocculted configuration in the 1991-1992 time frame, as well as the time required to more fully reduce and model the data collected during the mutual event season, supplemental funding was proposed and granted, which became the separate grant NAGW 3093 rather than the intended addition to NAGW 1991.

Because the latter grant essentially represents a continuation of the former grant, this final report covers both.

Observations

The primary observational goal of this project was to observe as many of the once-in-a-lifetime mutual events involving Pluto and Charon between 1984 and 1990. The principal site utilized for these observations was Mauna Kea Observatory, the principal facility was the University of Hawaii 2.24-m telescope, and the principal instrument was the Tinsley photometer (a dry-ice-cooled RCA C31034A photomultiplier. A few additional events involving particularly useful geometry were observed with the #1 0.61-m telescope at this same site. Because the time interval between events was half the orbital period of Charon, or about 3.2 days, events typically became visible from this site every 16 days (5 half-orbits), though pairs of events 3 days apart could be observed near opposition, when Pluto was available at reasonably low airmass for a significant number of hours.

Because the 16-day interval between observational opportunities is very close to half the lunar phase cycle, we were typically observing one type of event (superior conjunction, with

Charon behind Pluto, or inferior conjunction, with Charon in front of Pluto) in dark skies and the other type in bright skies. In an attempt to balance the signal-to-noise ratio for the two types of events and to cover some events at other longitudes, we proposed for observations at Cerro Tololo Interamerican Observatory in 1987, 1988, and 1989. Due to the vagaries of Telescope Allocation Committees, our essentially identical proposals were awarded time in 1987 and 1989, but not in 1988, when most of the central events involving totality occurred. The observations utilized the 1.5-m telescope equipped with ASCAP (Automatic Single Channel Aperture Photometer).

All together, over 50 events were successfully observed by us during the mutual event season, with coverage ranging from a few tens of minutes to about six hours. The typical time resolution was a little over a minute for the deeper events, while the integration time was lengthened slightly for the shallower events to improve the signal-to-noise ratio. At its best, the per integration photometric error was as small as 0.0025 mag, which we believe to be unprecedented for an object with an apparent visual magnitude of about 14.

<u>Support for other observers</u>

Of course, a unique opportunity such as this garnered worldwide attention, and we were instrumental in supporting the observational work of other observers. In particular, each year we computed the predicted circumstances for the following year's events, using our best available model for the system at the time. Acting on the belief that the highest photometric accuracy would be provided by using local comparison stars, we also obtained photometry of several candidate stars near the path of Pluto each year to identify those that provided a good color match to Pluto (to minimize color difference effects) while being bright enough to minimize dwell time on the stars without being too bright to cause significant nonlinearity effects at even the largest telescopes. The two best choices were also made known to other observers each year along with a red-blue pair to calibrate color terms. With one exception, all of this information was published annually, and we are grateful to The Astronomical Journal for providing excellent turnaround time for us. The exception was the 1990 season, for which the computations were done following the 1989 observations that extended through the summer. The Principal Investigator became a state-funded, tenure-track member of the teaching faculty effective 1989 July 1, and was responsible for nearly 400 undergraduate students that fall. The teaching responsibilities precluded completion of a paper to accompany the 1990 event circumstances, although the list of events times was still widely circulated to other observers via an informal newsletter called the *Ninth Planet News*. Nevertheless, we feel that it is important to complete the historical record in the refereed literature, so we plan to submit the 1990 event circumstances for publication, even though it is now after the fact. Because reasonably accurate event circumstances could not be computed until the first event had been detected, no such list has ever been published for the 1985 opposition. It is our intent to fill this void at the same time. As this is no longer an officially supported activity, it is a lower priority task.

<u>Modeling the Pluto-Charon system</u>

Our modeling efforts occurred in two distinct phases. The first phase involved the fitting of the mutual event data while solving for the orbital elements of Charon, the radii of Pluto and Charon, and large-scale albedos for the two surfaces. An important derived parameter from these results is the mean density of the system, which carries implications for the bulk composition and interior structure of the two bodies. The mutual event data did an excellent job determining the orbital period of Charon, its mean longitude, and the longitude of its ascending node. The orbital inclination is more poorly constrained, and the semimajor axis was not determined at all, hence we had to rely on other techniques to arrive at a reasonable value for this parameter. The inter-event timings provided a very good constraint on the orbital eccentricity for an orientation of the line of apsides perpendicular to the line of sight, but the orthogonal direction had to be constrained by intra-event timings, which are far less well-determined and in any event are coupled with the radii solutions. Hence we have some constraint on the orbital eccentricity, but not in a global sense.

The second modeling phase involved the production of albedo maps for the two bodies utilizing rotational lightcurve data and mutual event data. This aspect of the work was handled primarily by collaborator M. W. Buie (at that time here at the University of Hawaii, but later at the Space Telescope Science Institute, and now Lowell Observatory). The maps are, to first order, consistent with independently derived maps by Young and Binzel as well as the first resolved images of Pluto provided by the repaired Hubble Space Telescope and Faint Object Camera.

Individual masses

A significant limitation of the mutual event results is that only the system mean density is derived. To determine the individual densities, the barycentric wobble of the system needs to be measured. Thanks to the excellent seeing characteristics of the Mauna Kea site and more recent improvements in controlling the dome seeing, we felt that such a measurement could be attempted from the ground. We proposed for and were awarded portions of seven consecutive nights in 1992 February-March. Six of those nights yielded data, and the resulting Charon/Pluto mass ratio determination was 0.084 ± 0.015. Unfortunately, this result disagreed rather badly with an independent result obtained with the Hubble Space Telescope by Null *et al.* Neither party could identify any faults in the others' work, so both parties planned to repeat their observations. Although it was our intent to repeat the ground-based experiment while these grants were still active, two proposals for telescope time were denied for logistical reasons. A third proposal for telescope time was finally successful, but after these grants had expired. A renewal proposal has been submitted to, in part, work with these new data.

Linear scale of the system

Because the mutual event data only provide the radii of Pluto and Charon relative to the size of Charon's orbit, a strict comparison of the mutual-event-derived radii with stellar-occultation-based radii requires an accurate value for the semimajor axis of Charon's orbit. For many years, we relied on a determination of this quantity from speckle imaging of the system by Beletic *et al.*, though the systematic error in the radii contributed by this determination was comparable to the random error due to the mutual event data. Supposedly better values became available from the barycentric wobble experiments, though both of the first generation results indicated a smaller semimajor axis and therefore smaller radii, though the discrepant mass ratio results call those numbers into question.

A by-product of a series of new Hubble Space Telescope observations of the system is a new orbit determination for Charon. (The writer's participation in this work was partly supported by these grants.) They not only provide a much more accurate determination of the semimajor axis, they also revealed a detectable orbital eccentricity (consistent with the mutual event constraint). This new semimajor axis is surprisingly consistent with the old speckle result, which means it is larger than either of the barycentric wobble results. However, the ground-based barycentric wobble result may be small due to the fact that the observations with the highest weight were made near periapsis. The HST result has been revised upward following preliminary analysis of their 1993 repeat, and now appears consistent with our new result.

At the same time, new hypotheses regarding the structure of Pluto's atmosphere by Stansberry *et al.* have helped to place lower occultation limits on the radius of Pluto. As a result, it appears that we are finally converging on values for the radii of Pluto and Charon, and just in time for the new mass ratio results, which also appear to be converging.

Future work

As much as we have learned about the Pluto-Charon system from this work, there remain several unanswered questions. Of primary interest right now is the recently discovered orbital eccentricity for Charon. Estimates by S. Peale suggest that a collision energetic enough to excite an eccentricity as high as 0.0076 would come close to shattering Pluto. However, we have shown that some of the eccentricity can be explained by offsets between the center of body and the center of light caused by the surface albedo contrast on Pluto's surface. Clearly, improvements in our understanding of the origin of this orbital eccentricity are tied to improvements in the albedo models for the system. To this end, we need to incorporate into the model the new individual lightcurves of Pluto and Charon as provided by HST, as well as continue to monitor the system lightcurve evolution as the sub-Earth latitude continues moving northward.

Triton

Obviously, the primary thrust of this research was the Pluto-Charon system. However, the similarities of Triton to Pluto suggested that some attention be devoted to Triton as well. Of course, the Voyager 2 spacecraft flyby of Neptune would provide far more information about the object, so observations were limited to those that complemented the ones made by Voyager and served as a check on the color calibration.

Because of the proximity of Neptune, which is five to six magnitudes brighter than Triton and only 10 to 16 arcsec away, a new technique had to be developed to remove the background scattered light when doing aperture photometry using a single element detector (note that most of the Triton observations were made on the same nights as Pluto-Charon mutual event photometry, so use of the same instrument was dictated). This technique involved concentric apertures of about 6.6 and 9.4 arcsec centered on Triton. The modulation in signal from Triton due to the aperture function was calibrated using field stars, while the modulation in signal from the background was modeled as coming from two sources, one being the natural sky background, for which the effective area ratio was calibrated using blank sky fields, and the other being scattered light from Neptune, for which numerical integrations were performed over the two circular apertures to calibrate the signal modulation. A signal profile of Neptune taken from a CCD image of the system was utilized in these numerical integrations. Because of the small size of the smaller aperture, observations had to be restricted to nights when the seeing was both good and steady.

The resulting colors were compared with Voyager results for Triton in the 30-day report, and the agreement in the region of overlap is quite good.

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REPORT 1112
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AS OF JUNE 30, 1994

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422RF	6430	530	DRIVE DISK HARD EXTERNAL ENCLOSURE ~~400MB~~ 320MB 400 W power supply	01/94	F-94-216	1	351916	P75794	U	2,426.00

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